United States
Department of
Agriculture

Agricultural
Research
Service

MARC Beef Classification System

Objective Evaluation of Beef Tenderness and Cutability

Roman L. Hruska U.S. Meat Animal Research Center[1]
Clay Center, NE 68933

November 1999

[1]Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of other products that may also be suitable. For additional information contact M. Koohmaraie at telephone 402-762-4221, fax 402-762-4149, or e-mail at koohmaraie@email.marc.usda.gov.

MARC Beef Classification System

T. L. Wheeler, S. D. Shackelford, and M. Koohmaraie

PURPOSE

This bulletin is in response to inquiries on the potential application of technologies to objectively evaluate beef tenderness and carcass cutability (Figure 1). We will describe how these processes could be conducted manually for low volume applications. We also will describe an automated system for applying these technologies for on-line measurement of meat tenderness and carcass cutability. We will summarize the information regarding the merits of these technologies and we will explain why theses technologies must be conducted as described.

THE PROCESS

1. Carcasses are chilled conventionally. The left carcass side is ribbed conventionally and the ribeye is bloomed for quality grading. Simultaneously, the right carcass side is ribbed by a double-bladed reciprocating meat saw and a one-inch thick steak is removed (Figure 2).
2. For image analysis (Figure 3), steaks are placed flat on a non-glare surface and illuminated with lights. Images are captured using a 3 CCD color video camera, a software package, and a 200-MHz personal computer equipped with a RGB frame grabber.

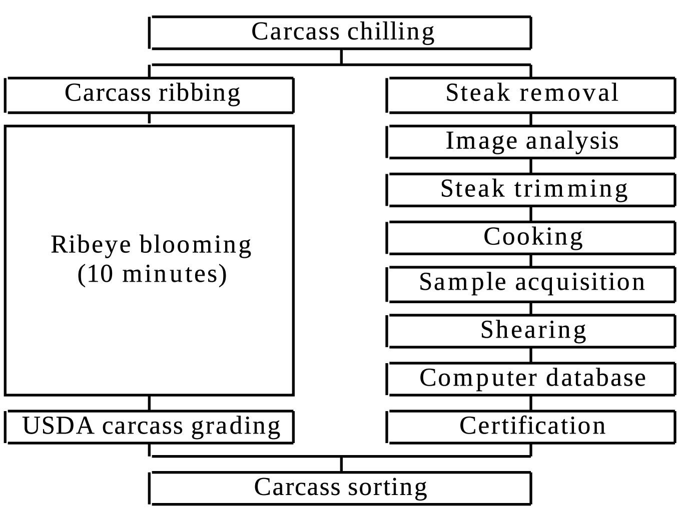


Figure 1. Flow chart of system for objective evaluation of beef tenderness and cutability.

Figure 2. Two straight, parallel cuts (2.54 cm apart) are made simultaneously through the posterior half of the 12th thoracic vertebra, longissimus, and adjacent fat perpendicular to both the long axis and split surface of the vertebral column. The cut proceeds to a point about 12.7 cm lateral to the lateral tip of the longissimus. A cut is then made perpendicular to the first two cuts to separate the lateral end of the steak from the carcass at a point 10.2 cm lateral to the lateral end of the longissimus. For "manual" tenderness classification, cuts are made using a double-bladed reciprocating meat saw.

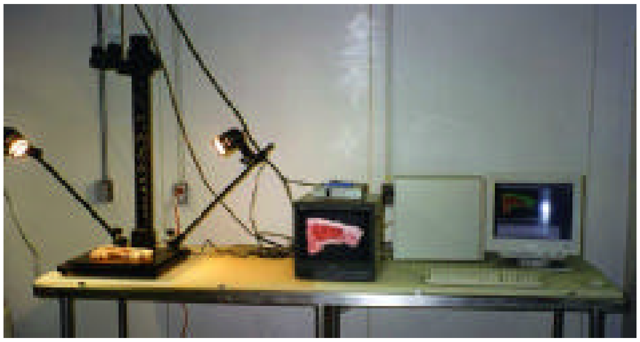


Figure 3. Image analysis equipment.

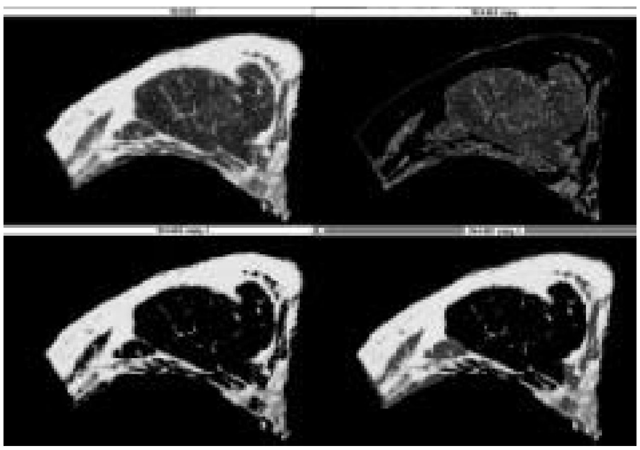


Figure 4. Images of a steak before analysis (top left), with the fat highlighted in black (top right), with the lean highlighted in black (bottom left), and with the biggest lean piece (EYEPIECE) highlighted in black (bottom right). Note that EYEPIECE is not necessarily limited to the longissimus.

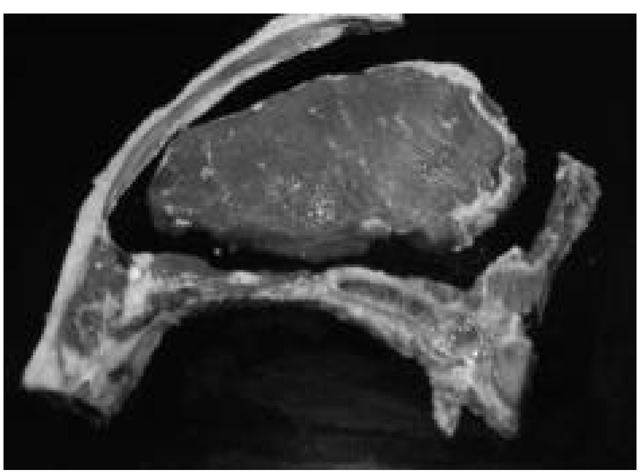


Figure 5. Steak is trimmed of fat and bone.

3. Images are captured and analyzed (Figure 4) automatically using a macro computing program. Image analysis is used to predict carcass cutability, longissimus area, subprimal cut weights, lean color, and marbling score.
4. Based on image analysis, the steak is trimmed of fat and bone (Figure 5). For automated tenderness classification, this step could be conducted

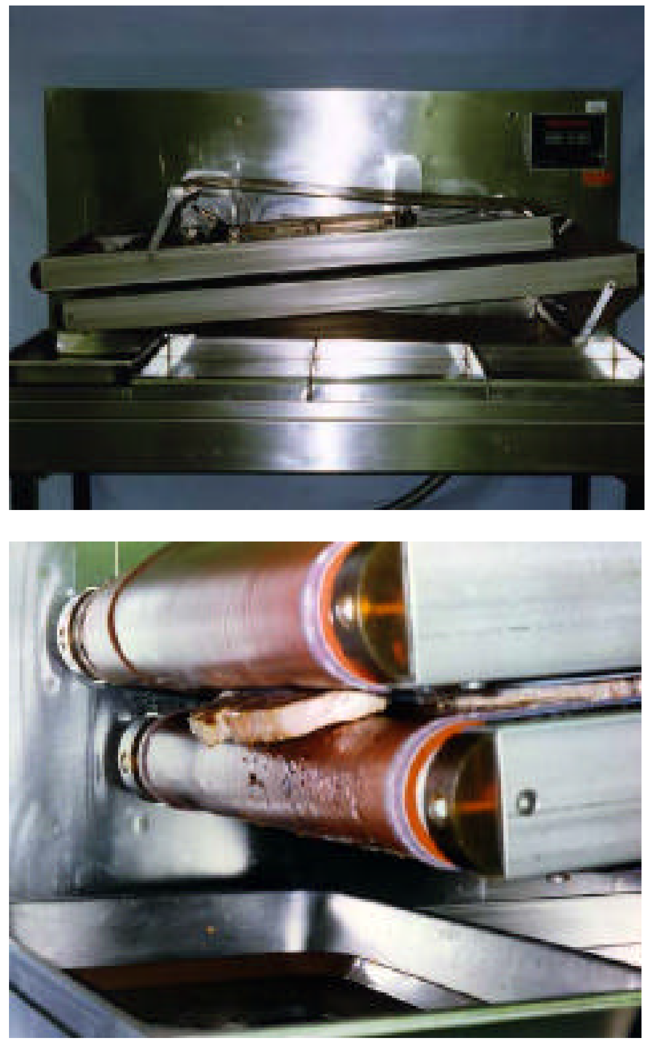
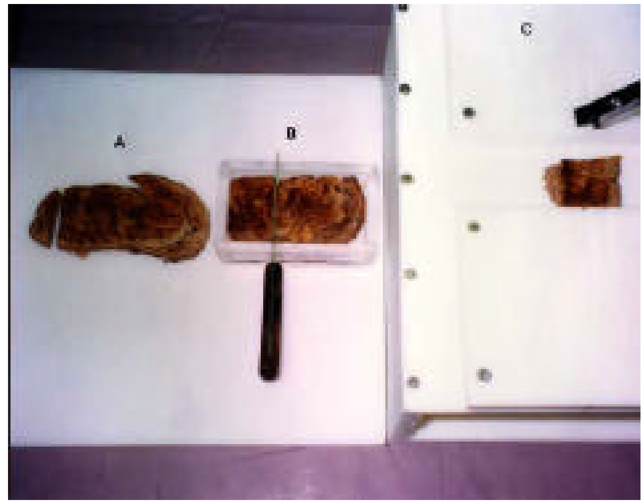


Figure 6. Belt grill (top). Steak is carried between two 260°C platens by two parallel Teflon belts. Total cooking time required to cook the steak from an internal temperature of about 5°C to an internal temperature of 70°C is 7.33 min. Total cooking time includes time required for the steak to enter the grill (1 min), pass between the platens (4.33 min), and exit the grill (.42 min) plus time for post-cooking temperature rise (1.58 min). Close-up view of cooked steaks exiting the belt grill (bottom).

using an automated water-jet trimming system.

5. The steak is cooked using a continuous-feed belt grill (Figure 6). Total cooking time is 7.33 min. Because consistency of degree of doneness is critical to accurate evaluation of tenderness, proper quality control procedures should be used to insure that the targeted degree of doneness is being achieved. Cooked steak internal temperature can easily be measured on a subsample of steaks using a hand-held thermometer and needle thermocouple (Figure 7).
6. Immediately after cooking, a 1-cm-thick, 5-cm-long slice is removed from each steak parallel to the muscle fibers (Figure 8). For automated tenderness classification, this step could be conducted using an automated water-jet trimming system.
7. Shear force is determined for each slice using an electronic testing machine (Figure 9). The data is captured electronically into the packing plants computer database and, thus, is available for record keeping, carcass sorting, and carcass valuation.

Figure 7. Confirming the end point temperature at the center of the cooked steak with a hand-held thermometer and needle thermocouple.



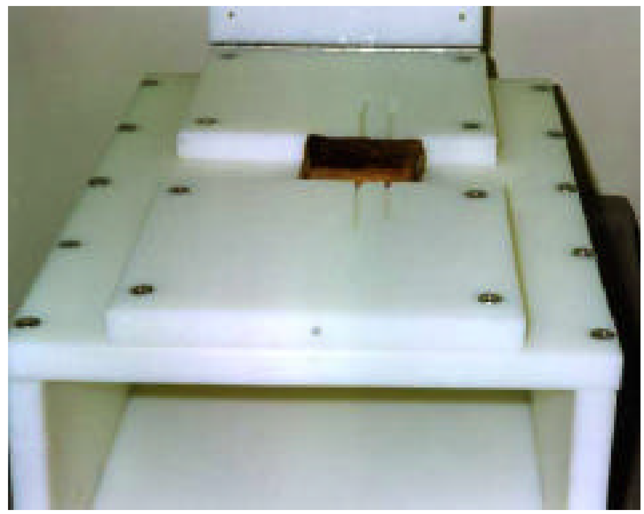


Figure 8. Slice acquisition equipment for "manual" tenderness classification of beef (top). Three samples are shown progressing through the process. A. The lateral end of the steak is removed by a straight cut across the longissimus at a point about 2 cm from the lateral end of the muscle. B. The cut (lateral) end of the steak is placed against the end of the miter box and a second cut is made parallel to the first cut at a distance of 5 cm from the first cut using the miter guides. C. The 5-cm-long portion is placed in the slice box and oriented such that the muscle fibers are oriented parallel to the slots in the box. A double-bladed knife is placed in the slots and used to remove a 1-cm-thick slice from the 5-cm-long portion. The resulting slice is uniformly 1-cm thick, 5-cm long, and consistently parallel to the muscle fibers. Close-up view of 5-cm long portion in slice box (bottom). Note slots in the slice box are at a 45° angle so that the slice is taken parallel to the muscle fiber orientation.

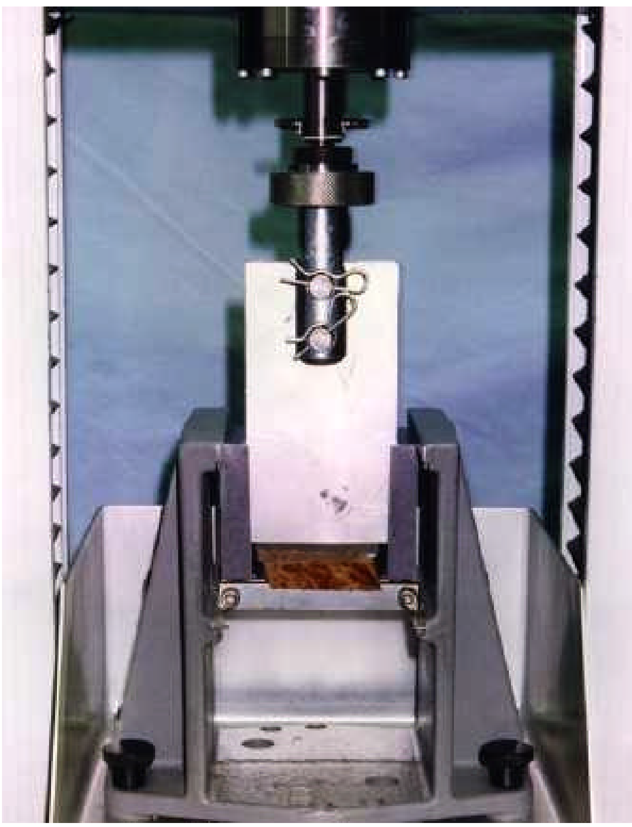


Figure 9. Electronic testing machine with computer interface showing measurement of slice shear force (top). The slice blade is 1.016 mm thick and has a half round bevel on the shearing end (bottom). The cooked longissimus slice is 1 cm thick, 5 cm long, and oriented such that the shearing action is perpendicular to the muscle fibers.

8. The process is completed during the 10 minutes that the ribeye is bloomed for quality grading and, thus, sorting of carcasses for fabrication would proceed conventionally.
9. Carcasses are fabricated and ribeye and striploin/shortloin are cooler-aged (0 to 3°C) a minimum of 14 days.

Important Details

· The steak dimensions are critical for accurate image analysis and belt grill cooking.

· The slice must be taken parallel to the muscle fibers.

· Slice dimensions must be consistent.

· The shearing blade must be 1.016 mm thick with a straight cutting edge that has a half-round bevel.

· Conducting any step of the process manually increases the possibility of human error, potentially resulting in reduced accuracy of the shear force measurement. A plan for maintaining consistent accuracy of all steps in the process must be in place.

· The shear force measurement needed for tenderness classification does not have to be made in the first few days postmortem. It can be made at any time postmortem that fits specific circumstances or needs as long as classification is adjusted accordingly. The effect of making the measurement at a later time is that more carcasses would be classified as "Tender" rather than "Intermediate" because a greater amount of aging would have already taken place before the measurement.

POTENTIAL AUTOMATION

We envision a fully-automated system that could accomplish these tasks in a high-volume operation (Figure 10).

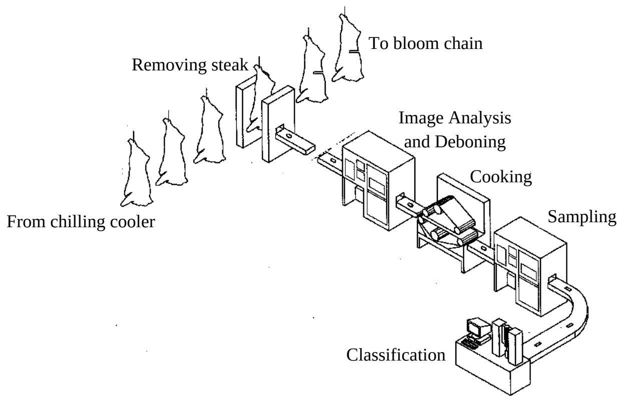


Figure 10. Schematic of the automated system for objective evaluation of beef tenderness and cutability.

COST ANALYSIS

These costs are estimates only. The reader is encouraged to use other numbers if deemed more appropriate.

The cost of a manual beef classification system is estimated at $65,000. For one year machine life and processing 100 carcasses per day, five days a week, 52 weeks per year, the cost of the equipment is $2.50 per head ($65,000/[100 x 5 x 52]). Including labor and sample costs, the cost of manual tenderness classification is estimated to be $8.50 per carcass (Table 1). Based on processing 26,000 carcasses per year, this cost would be equal to 2¢/lb for all steaks and roasts or 11¢/lb on the ribeye roll and strip loin from each carcass.

The cost of a fully automated system, once developed, is crudely estimated at $225,000. If one estimates the life of the equipment to be one year and assumes that each plant will process 3000 carcasses per day, five days a week, 52 weeks per year, then the cost of the equipment is 29¢ per head ($225,000/[3000 x 5 x 52]). Including labor and sample costs, the cost of automated tenderness classification is estimated to be $4.35 per carcass (Table 1). Based on processing 780,000 carcasses per year, this cost would be equal to 1¢/lb for all steaks and roasts or 7¢/lb on the ribeye roll and strip loin from each carcass.

The value of the information gained from objectively evaluating tenderness and cutability is partially dependent on how that information is utilized. Potentially, this information could be used in a value-based marketing system. Information could be shared with the production sector and used in genetic selection for cattle that optimize production efficiency, carcass composition and meat quality.

Table 1. Cost estimates of manual and automated beef classification

	Manual		Automated	
	$/carcass	$/cwt	$/carcass	$/cwt
Sample[a]	4.00	.57	4.00	.57
Labor[b]	2.00	.29	.06	.01
Equipment	2.50	.36	.29	.04
Total	8.50	1.21	4.35	.62

[a]The process requires devaluation of a 1" thick ribeye steak from each carcass. At one pound per steak, loss of one ribeye steak equates to $4.00.

[b]It is estimated that one additional employee (8 man-hours) will be required for beef classification (automated or manual). At $25 per hour and 400 (automated) or 12.5 (manual) carcasses processed per hour, labor cost will be 6¢ (automated) or $2.00 (manual) per carcass.

The value of the information gained from objectively evaluating tenderness is also dependent on market forces and the distribution of the different tenderness classes (Table 2). These distributions indicate a much higher percentage of "Tender" carcasses than we currently have for Prime and Top Choice. Ten-

Table 2. Distributions of carcasses based on current USDA quality grades and tenderness classification

	Percentage
-----------USDA quality grade distribution[a] -----------	
Prime	1
Top Choice	11
Low Choice	36
Select	47
Standard	5
------------Tenderness class distribution[b] -----------	
Tender	49
Intermediate	48
Tough	4

[a]Distribution of quality grades in the 1995 National Beef Quality Audit.

[b]Distribution of tenderness classes taken from MARC experimental data on 14 month old, grain-fed, commercially-slaughtered, crossbred steers and heifers (n = 696). This distribution may differ depending on the sample tested.

derness classification would enable identification of a significant number of carcasses with tender meat that are currently discounted because of lower levels of marbling. Furthermore, classification based on tenderness would result in increased consumer satisfaction (because the product delivered what was expected), and would encourage more efficient production of lean and tender beef.

WHY USE SHEAR FORCE?

Ideally, we would like to be able to measure (predict) meat tenderness with a rapid, automated, tamper-proof, noninvasive, accurate instrument. Numerous technologies have been investigated including ultrasound, elastography, near-infrared (NIR) spectroscopy, video image analysis (VIA), Tendertec®, and connective tissue probes. None of these technologies have successfully predicted meat tenderness because these technologies are all based on indirect measurements that are not capable of sensing the subtle changes in raw meat that are responsible for variation in cooked meat tenderness.

Previously, we explored prediction of meat tenderness using numerous muscle biochemical traits potentially related to meat tenderness. We first concentrated our efforts around the single factor most responsible for variation in tenderness (the inhibitor of the calpain enzyme, calpastatin). However, we have only been able to account for about 40% of the variation in beef tenderness using calpastatin activity at 1 d postmortem. We concluded that calpastatin activity by itself would not predict meat tenderness with sufficient accuracy for use in a classification system. We then evaluated the possibility of combining other traits, such as muscle pH, and temperature, carcass grade traits, and sarcomere length. We were able to explain 70% of the variation in tenderness using multiple traits. However, we soon realized that it would not be feasible to make all the measurements needed for that level of prediction accuracy under commercial conditions. At that point, we came to the conclusion that indirect measurements would never be sufficiently accurate and amenable to industry application. Therefore, we would have to measure tenderness directly.

The best direct measure of tenderness with the greatest chance to be successfully adapted for automated, on-line tenderness measurement is Warner-Bratzler shear force, which is routinely used by meat scientists to measure meat tenderness. To be successfully adapted for large processing plants, automated shear force would have to be measured early postmortem (when grading is normally done), be automatable, make the measurement in the 10 to 15 minute time frame that is available, and be accurate enough to provide useful classification of beef based on tenderness. We first evaluated existing data to see if shear force at 1 or 2 days postmortem would provide an accurate prediction of tenderness after aging 14 days. We found that we could segregate beef carcasses into three tenderness classifications (we call them "tender", "intermediate", and "tough") by using shear force at 1 or 2 days postmortem with 90.7% accuracy (Figure 11).

Having found day 1 or 2 shear force to be successful, we started making the modifications to the normal Warner-Bratzler shear force procedures that would speed up the process to fit the time constraints in the packing plant and to make it easier to automate. These modifications were made by utilizing rapid cooking technology that already existed in the food service industry and by changing the sample that is sheared from six, 1/2-inch diameter cores to one, 1-cm (0.4 inches) thick slice. The modified (slice) shear force segregated carcasses into the three grades with 94% accuracy (Figure 12).

The accuracy of classification depends on the accuracy of the shear force measurement and the distribution of tenderness in the animals sampled. Likewise the percentage in each of the three tenderness categories depends

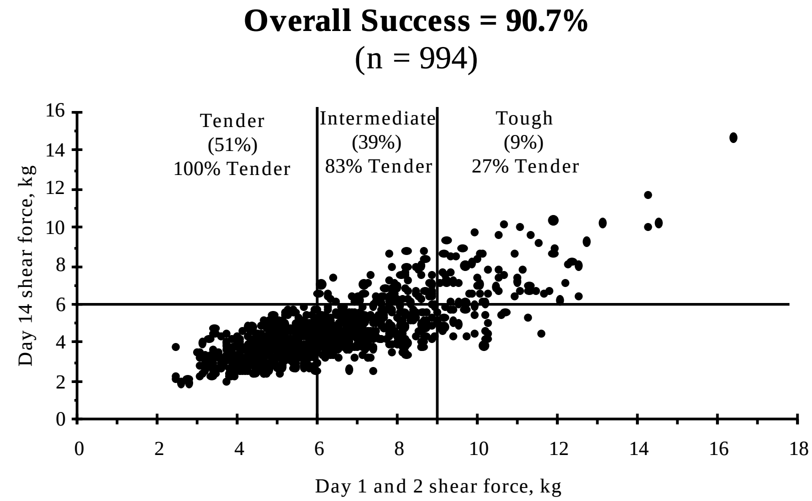


Figure 11. Accuracy of tenderness classification into three categories using Warner-Bratzler shear force. The percentage of all carcasses assigned to a given category is shown in parentheses.

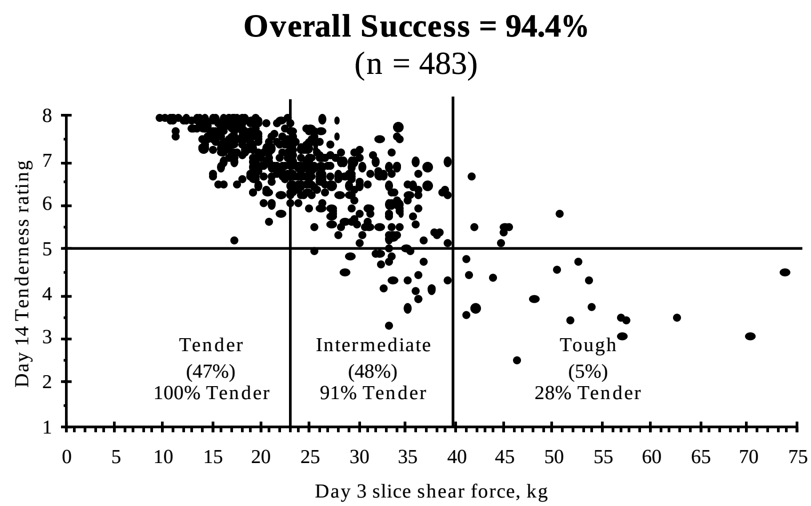


Figure 12. Use of manual tenderness classification at 3 d postmortem to predict longissimus tenderness ratings at 14 d postmortem (r = -.78). For 94.4% of the samples evaluated at 3 d postmortem, tenderness classification accurately predicted whether or not the trained sensory panel would rate the sample as "Tender" at 14 d postmortem. All, 91%, and 28% of the samples in the "Tender", "Intermediate", and "Tough" classes, respectively, were rated "Slightly Tender" or higher by the trained sensory panel at 14 d postmortem. Parenthetical values below the class names indicate the percentage of the total population in each class.

on the animals sampled and, thus, can vary considerably.

Because there is variation in chill time before grading (due to use of 24-, 36-, or 48-hour chill times at different plants and due to weekend schedules), carcasses potentially could come out of the chill cooler for grading anytime from 1 to 5 days postmortem. Thus, the classification system must adjust for the actual time postmortem that the classification takes place.

A prediction method that is highly-accurate should not be discarded simply because it is invasive. Rather, this system should be compared to noninvasive systems on a cost/benefit basis.

WHY USE A COOKED, 12TH RIB STEAK?

All attempts to measure longissimus tenderness using raw muscle have been unsuccessful. There is very little variation in mechanical measures of tenderness of raw muscle, and no association between measures of tenderness of raw and cooked muscle. Thus, tenderness must be measured on cooked meat.

As with the current USDA quality grading system, the shear force measurement must be made directly on the longissimus (ribeye). This muscle has by far the most variation in tenderness and the most animal-to-animal variation in tenderness (as compared to the high percentage of random, non-repeatable variation in other muscles). Measurement on the longissimus enables one to classify the ribeye roll and strip loin with a high degree of accuracy. However, the tenderness of the longissimus is not highly associated with tenderness of the other muscles. This has two implications: 1) a less expensive muscle cannot be used instead of the longissimus to measure tenderness, 2) a tenderness classification of the ribeye roll and strip loin cannot be applied indiscriminately to all other cuts from that carcass (i.e., although other cuts from carcasses classified as "tender" tend to be more tender than those cuts from carcasses classified as "tough", the association is not high for most muscles). Thus, all cuts from a carcass whose longissimus has been identified as "tender" cannot be guaranteed "tender". Because the association of longissimus tenderness to tenderness of other cuts is not high, if all cuts are to be marketed based on the tenderness classification of the longissimus (ribeye), we suggest marketing the cuts from a carcass as indicated in Table 3. However, the advantage from

Table 3. Potential tenderness categories for all beef cuts

I	II	III	IV
"Tender" Ribeye "Tender" Strip All Tenderloins All Top Blades	"Intermediate" Ribeye "Intermediate" Strip "Tender" & "Intermediate": Top sirloin Shoulder Clod Chuck roll Top round Bottom round Eye of round Sirloin tip	All "Tough" cuts All Briskets All Flank steaks	All Tenderized Cuts

I: These cuts will always be tender.

II: Most, but not all, of these cuts will be tender. These cuts will be more tender than corresponding cuts from "Intermediate" carcasses.

III: These cuts are probably tough and should be priced accordingly or tenderized.

IV: These cuts are probably tender and should be priced accordingly. Depending on marketing strategy they may be labeled separately or included in other labels, but should not be included with category I.

classification of only the ribeye roll and strip loin would probably more than justify the cost.

The steak should be removed from the 12th/13th rib because this is where the carcass would be ribbed anyway. Thus, the process of removing a steak accomplishes ribbing at the same time so that USDA quality grading can be applied as usual if desired. The steak used for shear force measurement actually comes from the area where two wedge pieces occur at the ends of the ribeye roll and strip loin due to the angle of ribbing while following the curvature of the rib. Thus, the steak utilized for shear force is not a full value steak.

WHY IMAGE ANALYSIS?

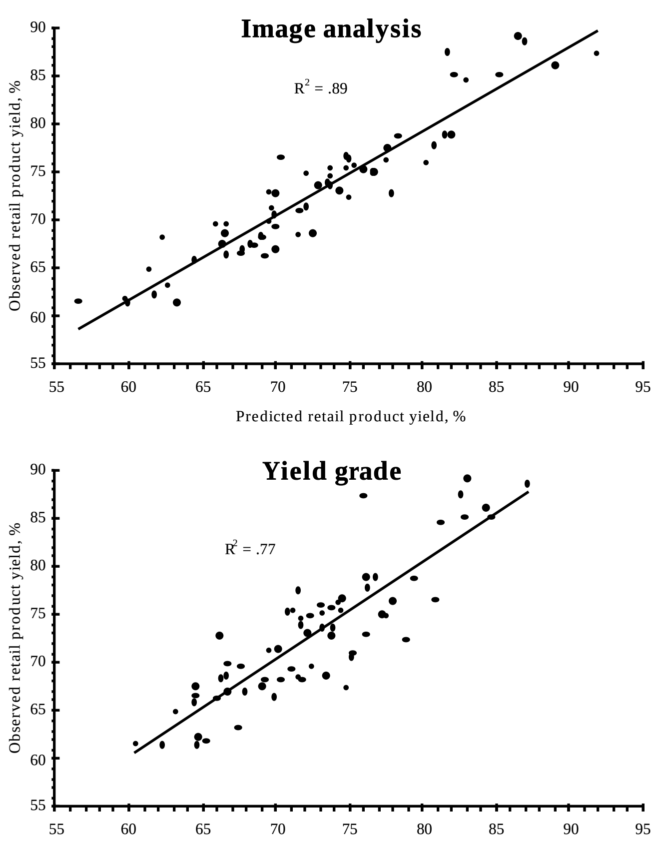


Figure 13. Comparison of the ability of image analysis and yield grade to predict retail product yield (n = 66).

Because tenderness classification requires that a 12th rib cross section be removed from each carcass, it provides an easy opportunity to also assess carcass yield traits by image analysis of the cross section. Image analysis accounted for more of the variation in retail product yield (89% vs 77%) and retail product weight (95% vs 90%) than did calculated “expert” yield grade (Figure 13). Thus, it would appear likely that this system would be much more accurate than on-line graders at estimating beef cutability. Also, image analysis accurately predicted longissimus area (R^2 = .88). For most subprimals, the combination of image analysis-predicted retail product yield and hot carcass weight accounted for more of the variation in subprimal weight than did the combination of calculated yield grade and hot carcass weight.

We have developed a macro computer program that could be used in conjunction with the system we have described in this paper. Less than 9 seconds is required to capture the image, conduct image analysis, and output the data to a computer data base. Thus, this technology could be used to evaluate up to 400 carcasses per hour.

This image analysis system could be used in combination with tenderness classification to accurately characterize beef for carcass cutability, longissimus area, subprimal cut weights, and tenderness. These tools should help facilitate the development of value-based marketing systems.